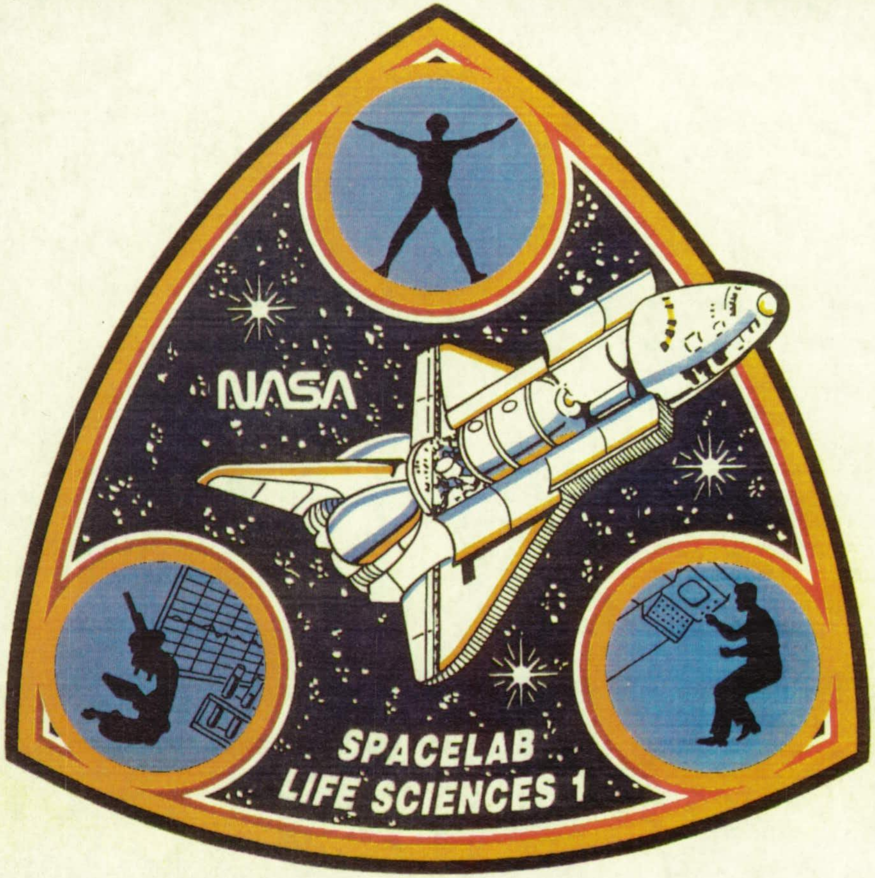
SLS-1 Flight Experiments Preliminary Significant Results

January 1992



A SUMMARY OF PRINCIPAL INVESTIGATORS' 180-DAY REPORTS

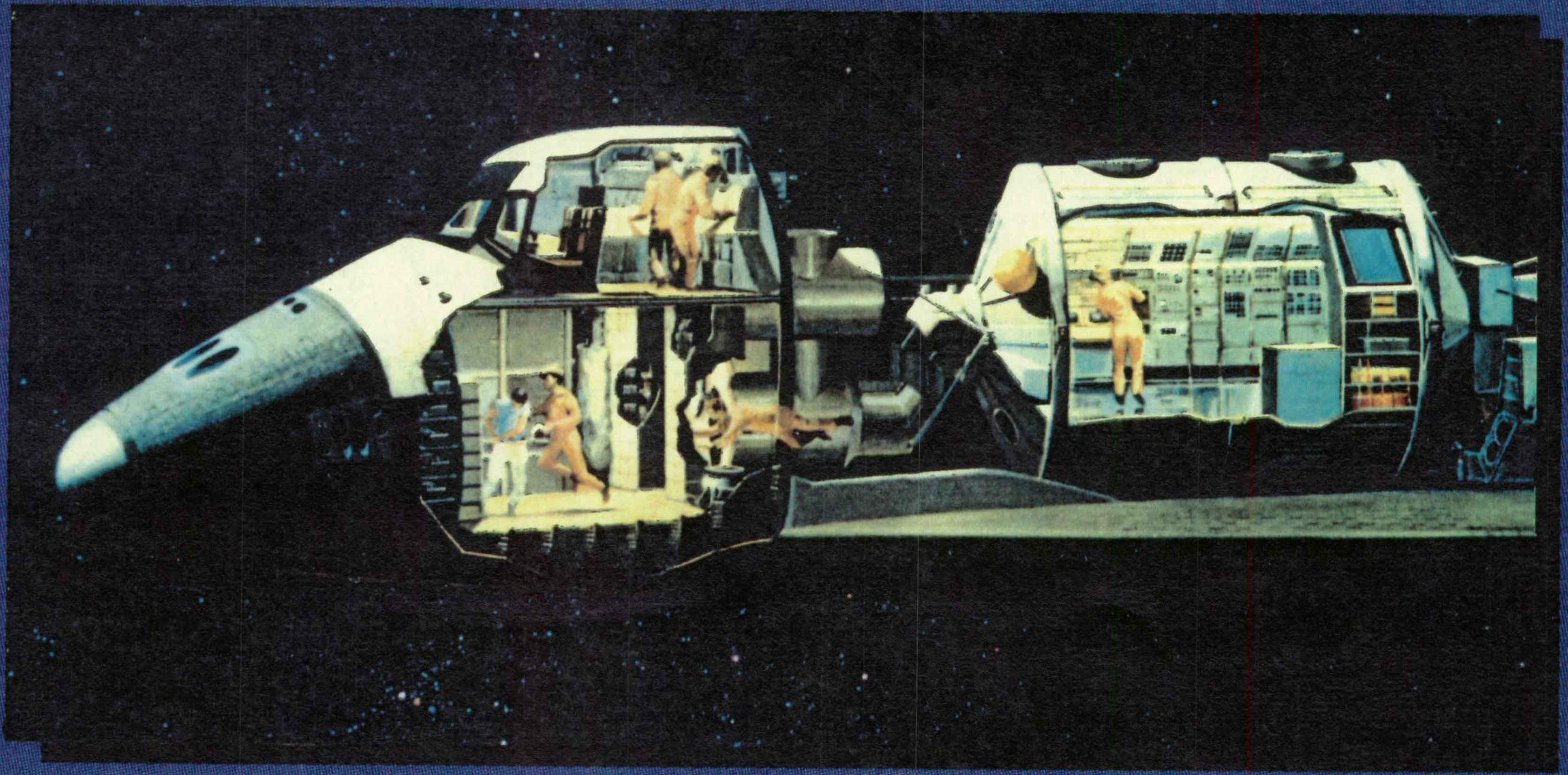
SLS-1 CREW

Clockwise from back left:
O'Connor, Jernigan, Hughes-Fulford, Guiterrez, Seddon, Bagian, Gaffney

SPACELAB LIFE SCIENCES 1

Spacelab Life Sciences 1 (SLS-1) is the first of a series of dedicated life sciences Spacelab missions designed to investigate the mechanisms involved in the physiological adaptation to weightlessness and the subsequent readaptation to 1 gravity (1 G). Hypotheses generated from the physiological effects observed during earlier missions led to the formulation of several integrated experiments to determine the underlying mechanisms responsible for the observed phenomena. The 18 experiments selected for flight on SLS-1 investigated the cardiovascular/cardiopulmonary, regulatory physiology, musculoskeletal, and neuroscience disciplines in both human and rodent subjects. The SLS-1 preliminary results gave insight to the mechanisms involved in the adaptation to the microgravity environment and readaptation when returning to Earth. The experimental results will be used to promote health and safety for future long duration space flights and, as in the past, will be applied to many biomedical problems encountered here on Earth.

Arnauld E. Nicogossian, M.D.
Director, Life Sciences Division
National Aeronautics and Space Administration



Spacelab provides the capability to perform life sciences research in space

GOALS

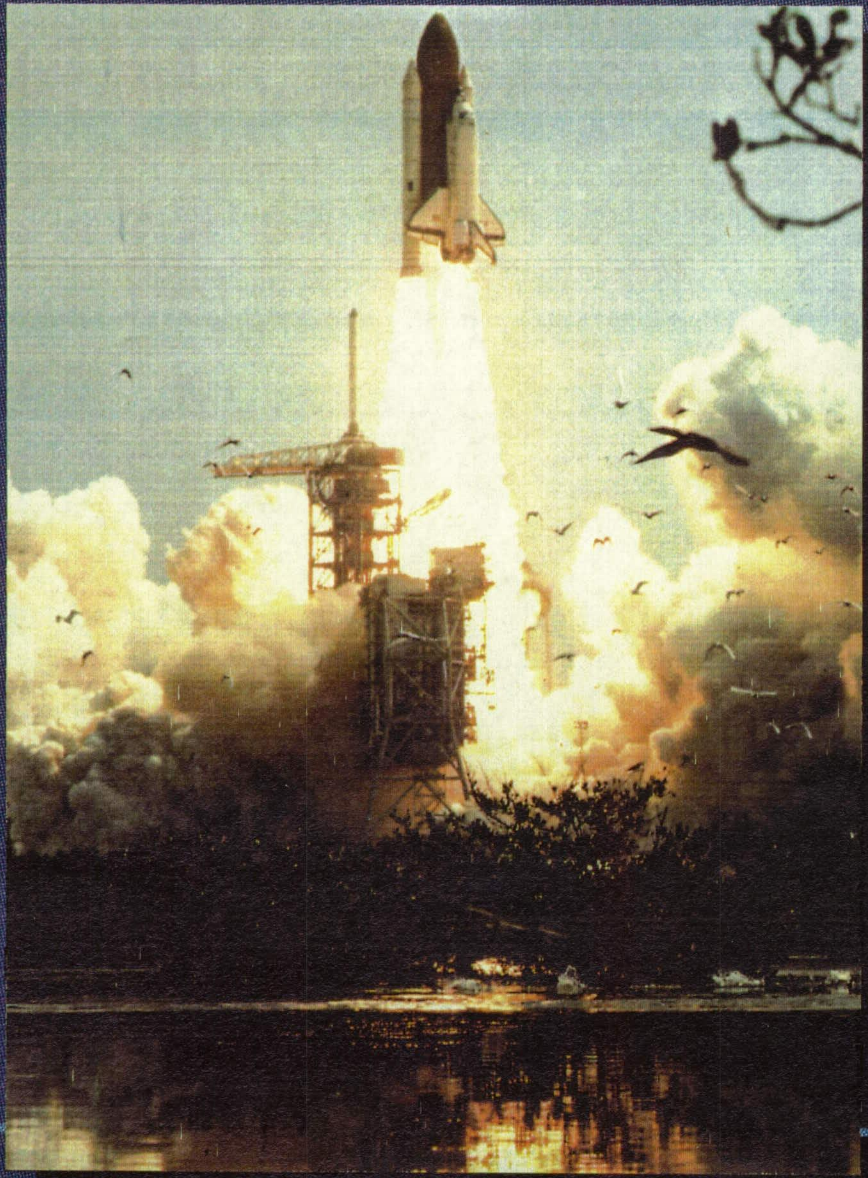
LIFE SCIENCES PROGRAM

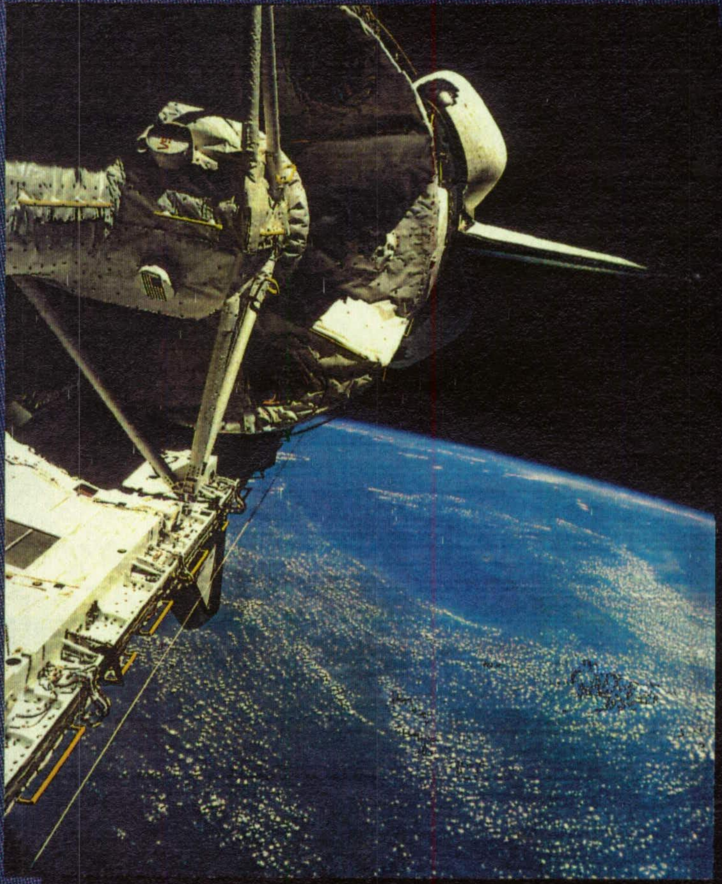
- Ensure the health, safety, and productivity of humans in space
- Acquire fundamental scientific knowledge concerning space biological sciences

SPACELAB LIFE SCIENCES 1 MISSION

- Study the mechanisms, magnitudes, and time courses of physiological changes that occur during space flight
- Investigate the consequences of the body's adaptation to weightlessness and readjustment to 1 G
- Test the validity of using rodents as human models for space flight research

SLS-1 was launched on June 5, 1991





MISSION PROFILE

LAUNCH: June 5, 1991

DURATION: 9 days

CREW: 4 Payload crewmembers
3 Orbiter crewmembers

Research was conducted in the following disciplines:

- Cardiovascular/Cardiopulmonary
- Regulatory Physiology
- Musculoskeletal
- Neuroscience

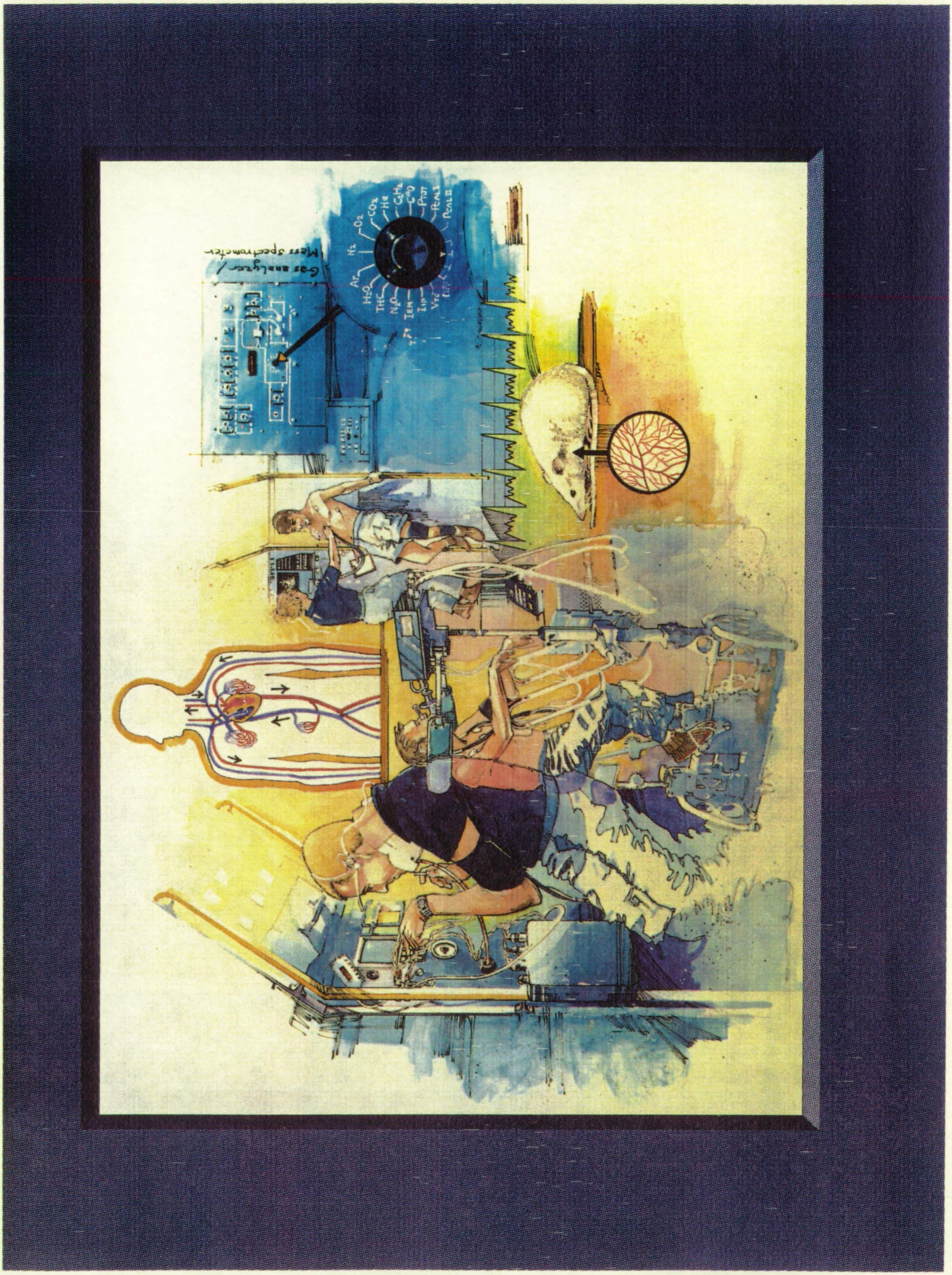
The primary payload consisted of 18 investigations:

- 10 utilized human subjects
- 7 utilized rodents
- 1 utilized jellyfish

The experiments were developed by an international team consisting of 17 Principal Investigators and 35 Co-Investigators from 4 countries:

- Australia
- Canada
- Switzerland
- United States

CARDIOVASCULAR/ CARDIOPULMONARY DISCIPLINE



Gas analyzer / Mass spectrometer

CARDIOVASCULAR/CARDIOPULMONARY

OVERVIEW

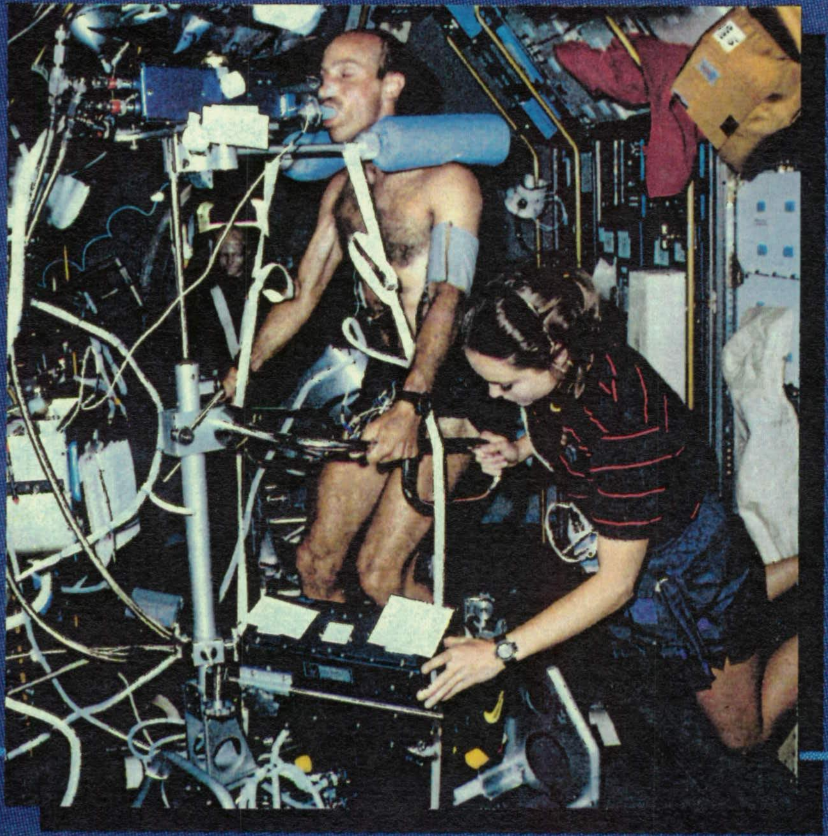
Space flight has been shown to cause changes in the cardiovascular/cardiopulmonary (CV/CP) system. The changes observed in previous space flights include an increase in heart rate and blood pressure, a decrease in lung capacity and cardiac response to exercise, and orthostatic intolerance.

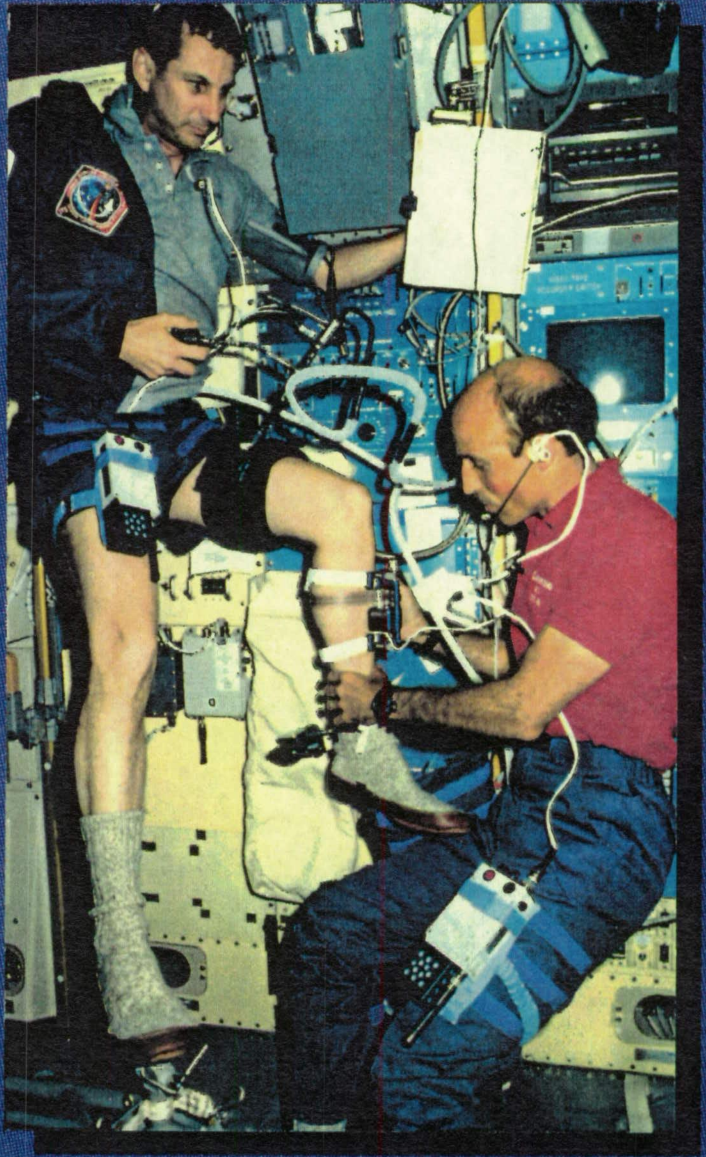
Four experiments were conducted on the SLS-1 mission to investigate the mechanisms contributing to the CV/CP adaptation and readaptation to 1 G.

EXPERIMENT OBJECTIVES

- To determine how acute and prolonged exposure to weightlessness affects the CV/CP response to stress induced by exercise
- To investigate acute changes in CV function and cardiac dimensions at rest and during exercise
- To compare pulmonary function during weightlessness to pulmonary function at 1 G
- To quantify CV/CP deconditioning by examining the carotid baroreflex receptors that control heart rate and blood pressure

CV/CP measurements were made before and during exercise





RESULTS OF CARDIOVASCULAR/CARDIOPULMONARY INVESTIGATIONS

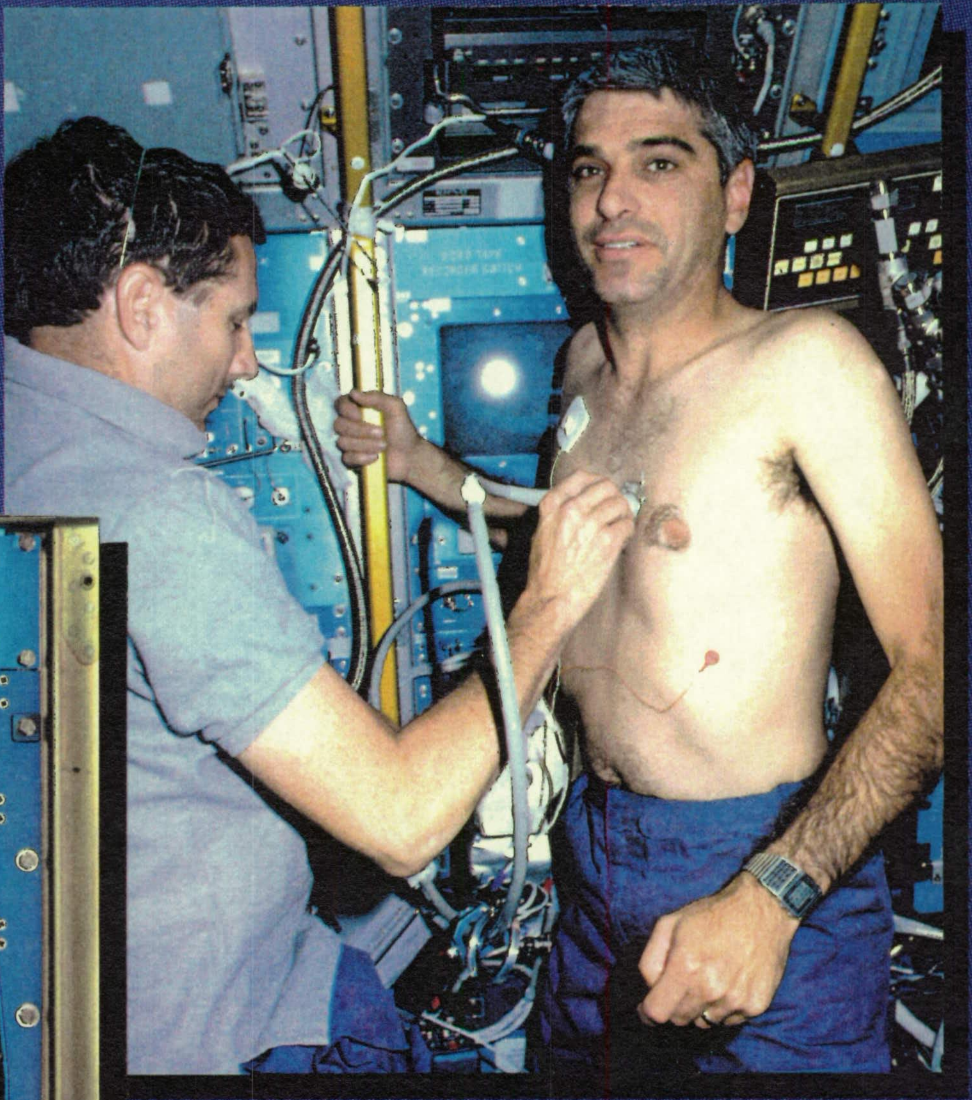
EXERCISE CAPABILITY

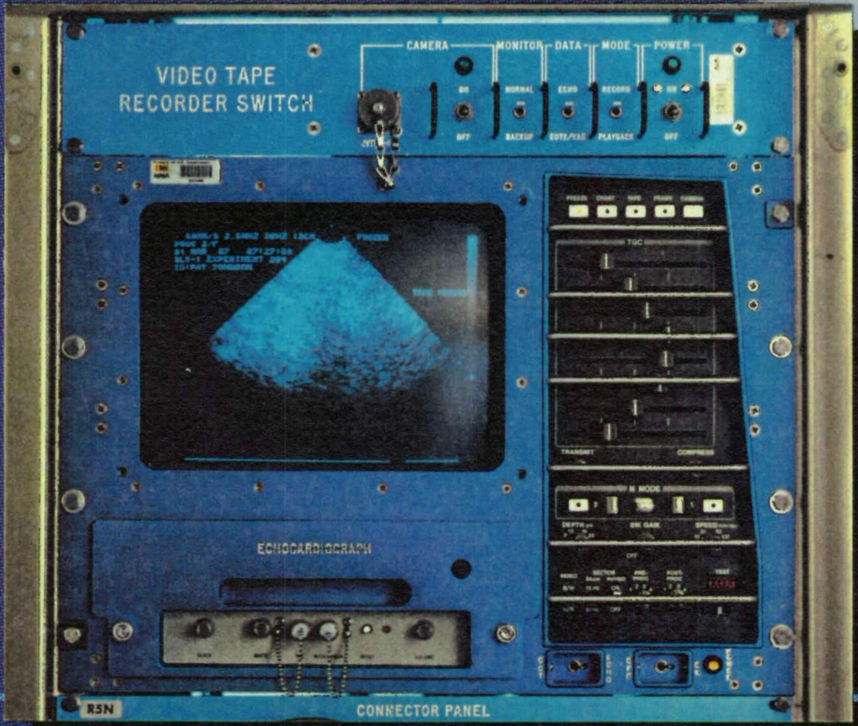
Exercise capability, for both moderate and maximum exercise levels, was reduced after flight due to the decrease in stroke volume, cardiac output, and oxygen uptake. Exercise capability had nearly returned to preflight levels within 7 days.

RESPIRATORY SYSTEM

Increases were observed during flight in the pulmonary capillary blood volume, the diffusing capacity of carbon monoxide, and the membrane diffusing capacity. This suggests that interstitial pulmonary edema, contrary to prior theory, is unlikely.

Echocardiography was performed to study heart function





RESULTS OF CARDIOVASCULAR/CARDIOPULMONARY INVESTIGATIONS (Concluded)

ORTHOSTATIC INTOLERANCE

During flight, stroke volume increased and heart rate decreased, allowing cardiac output to remain unchanged.

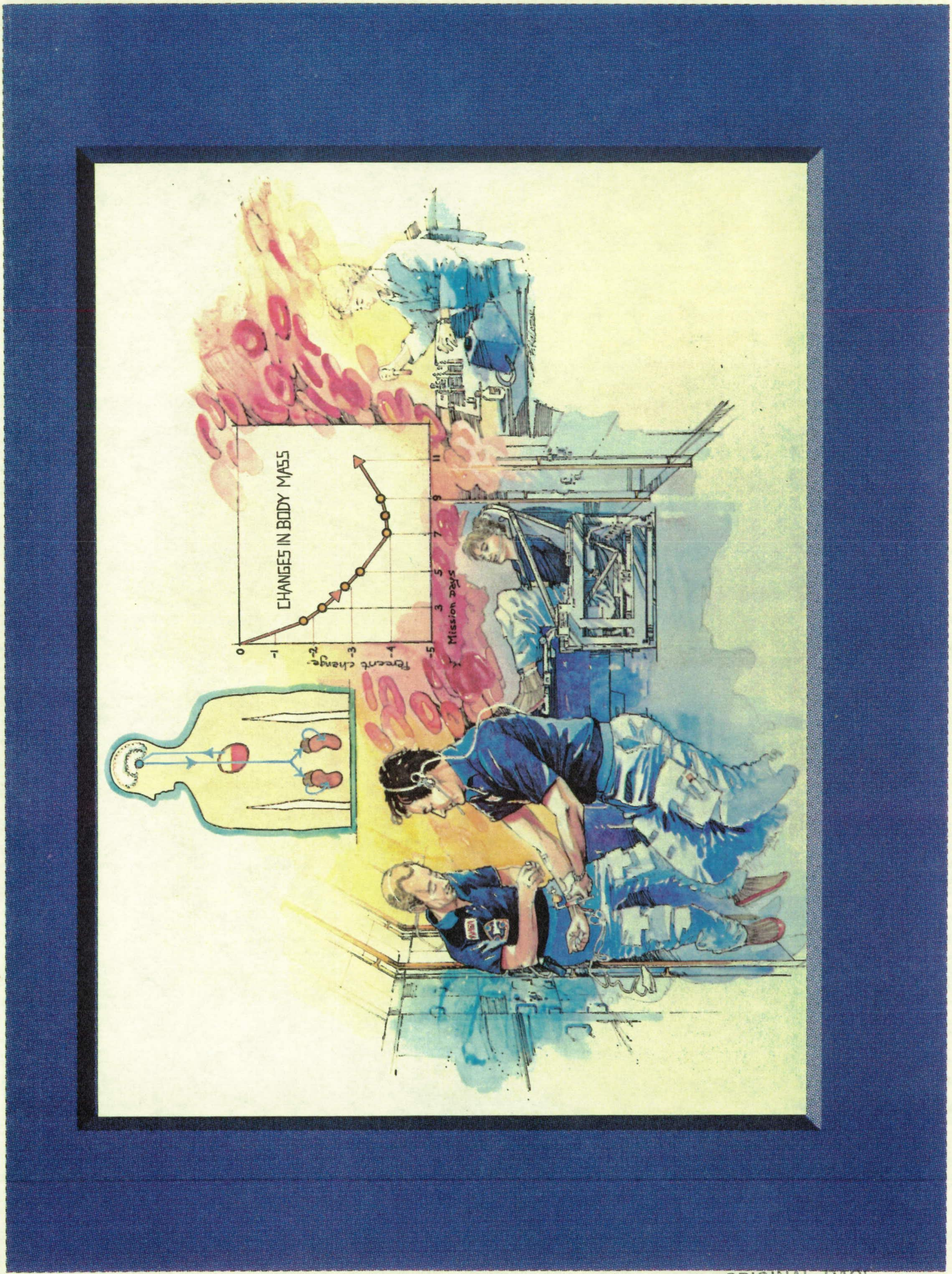
A postflight orthostatic intolerance was observed. This intolerance was characterized by a larger postural decrease in stroke volume, only partially compensated by an increased heart rate response, resulting in a decreased cardiac output.

Exposure to weightlessness leads to a degradation of human baroreflex function during flight and contributes to orthostatic intolerance after flight.

CENTRAL VENOUS PRESSURE

Central venous pressure fell below preflight levels following entry into microgravity. This result is not consistent with ground-based analog results. In light of this observation, current concepts of CV adaptation may require revision.

REGULATORY PHYSIOLOGY DISCIPLINE


CHANGES IN BODY MASS
Percent change
0
-1
-2
-3
-4
-5
Mission days
3
5
7
9
11

REGULATORY PHYSIOLOGY

OVERVIEW

The Regulatory Physiology discipline consists of the renal/endocrine, the circulatory, and the immunological systems. Changes that occur during early space flight include a headward fluid shift and a decrease in total body fluid, red blood cell (RBC) mass, and circulating lymphocytes. The mechanisms causing the changes, the time of onset of the physiological response, and the adaptation to weightlessness are not completely understood.

Five experiments on the SLS-1 mission investigated the various systems of the Regulatory Physiology discipline.

EXPERIMENT OBJECTIVES

Renal/Endocrine System

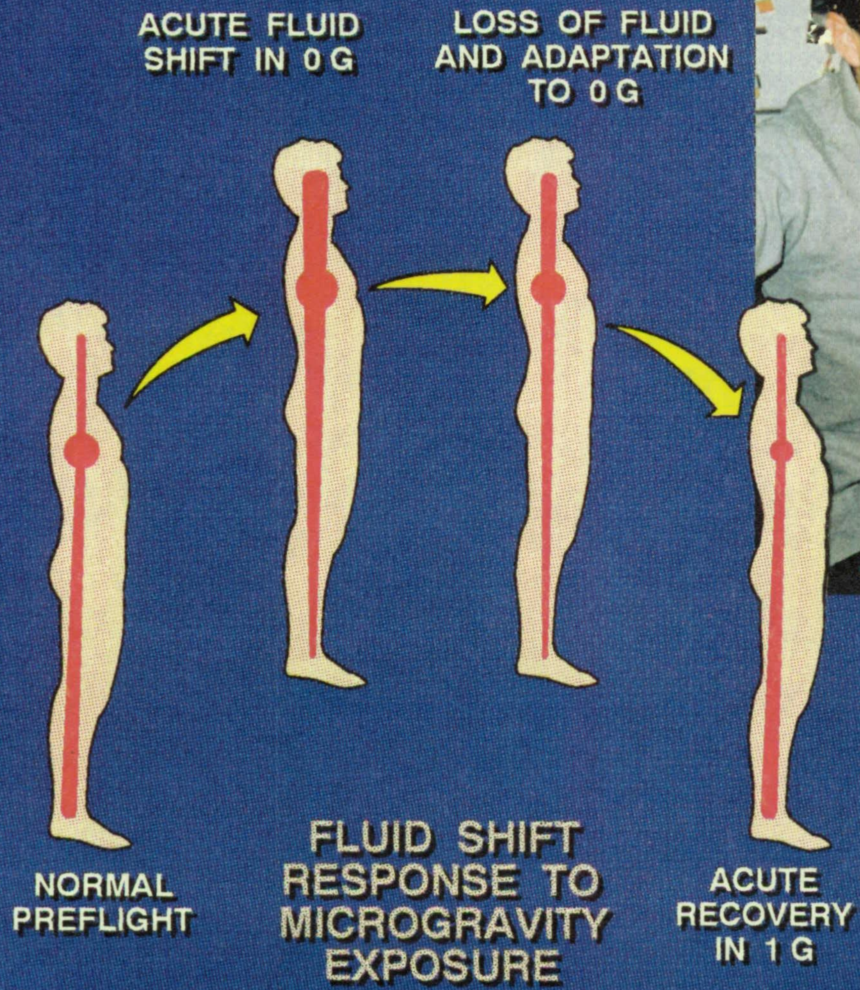
- To investigate the acute and adaptive changes in the fluid, electrolyte, and hormonal response to the headward fluid shift experienced in weightlessness

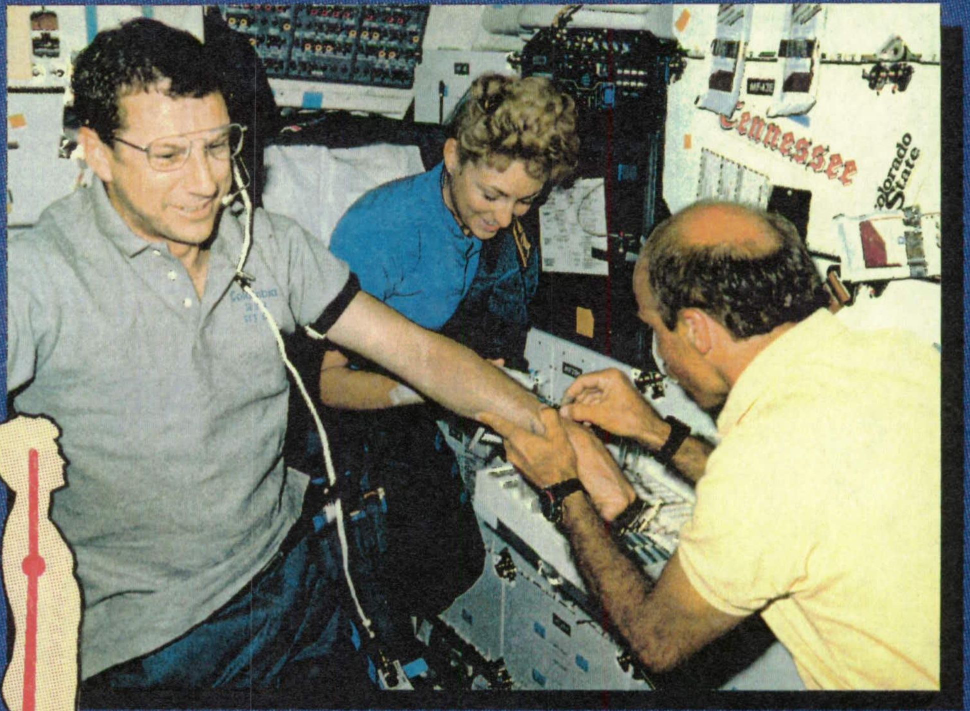
Circulatory System

- To determine if the decrease in RBC mass is due to suppressed production or increased destruction of RBC in 0 G
- To examine the reduction in the circulating RBC mass and plasma volume in human subjects and rodents

Immunological System/Biotechnology

- To study the effect of weightlessness on lymphocyte activation and proliferation





Samples were collected to study fluid volume regulation mechanisms

RESULTS OF REGULATORY PHYSIOLOGY INVESTIGATIONS

RENAL/ENDOCRINE SYSTEM

Renal Function

Renal filtration rate was elevated during flight (Figure 1). Bed rest studies and indirect measurements of filtration rate on previous space flights have shown a decrease.

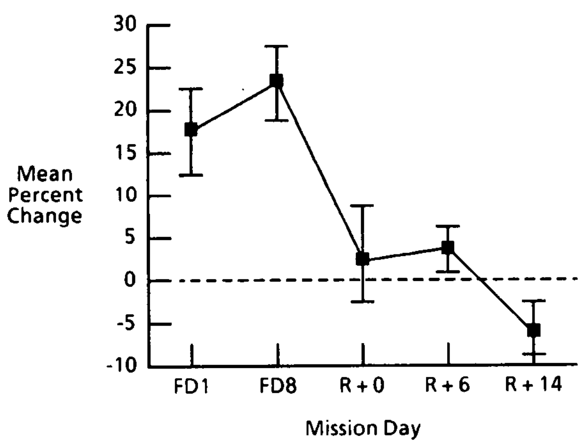


Figure 1. Renal Filtration

Fluid Regulation and Fluid-Regulating Hormones

Total body water (TBW) volume decreased early during flight due to the decrease in extracellular fluid (ECF) volume, especially in plasma volume (PV). The TBW, PV, and ECF values increased toward preflight values during flight (Figure 2). The response of the associated fluid-regulating hormones supported the observations of body fluid changes.

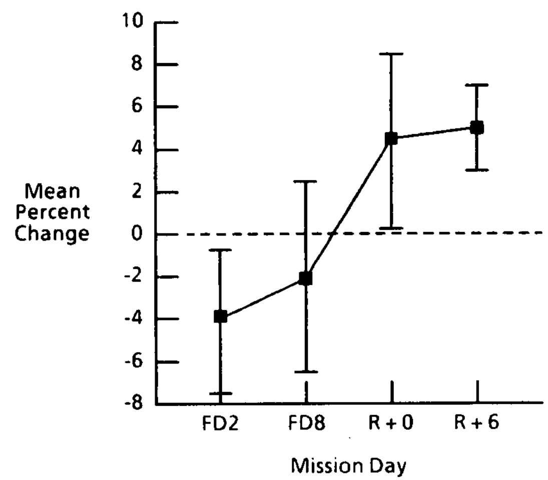
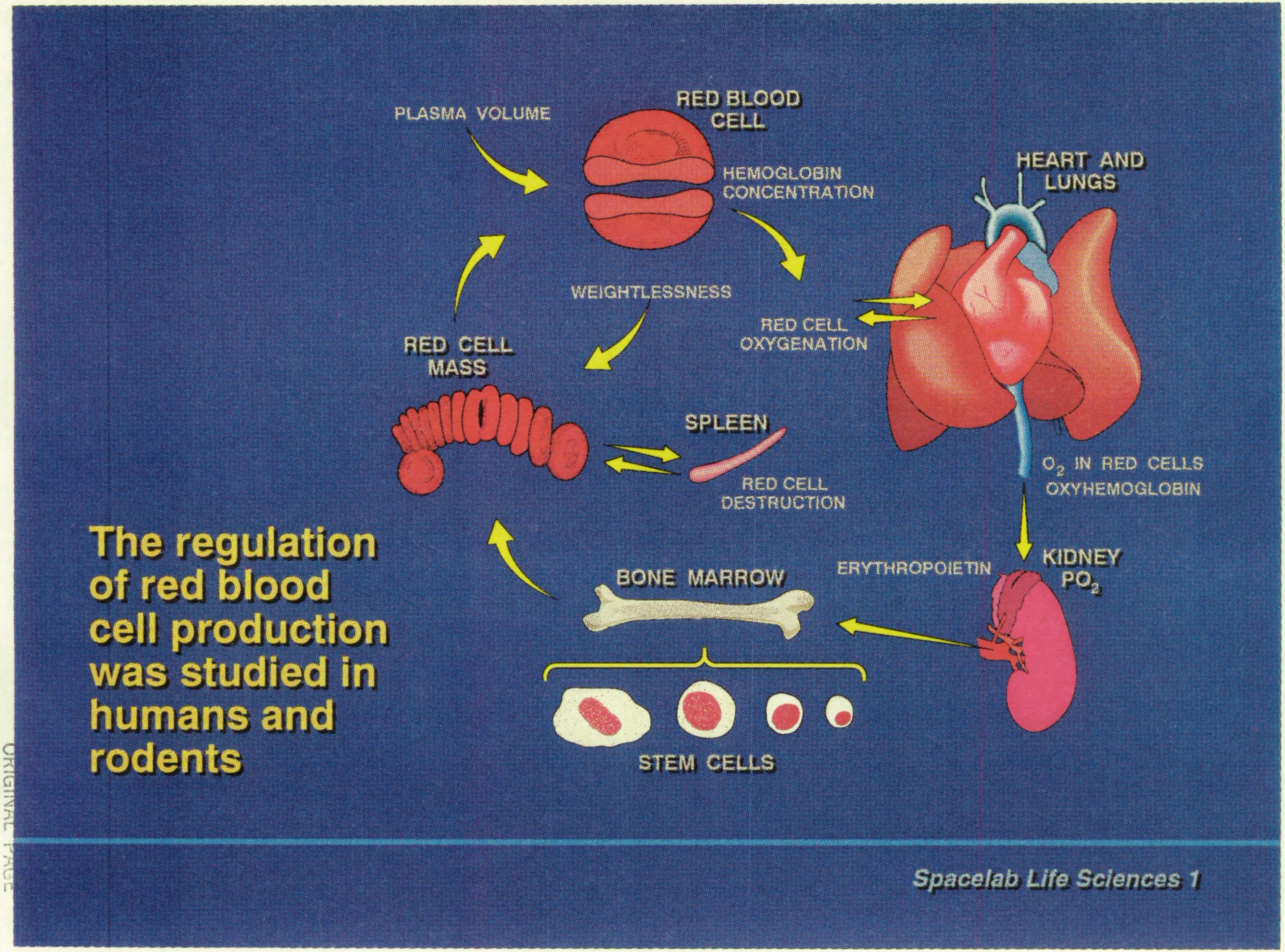


Figure 2. Total Body Water


The regulation of red blood cell production was studied in humans and rodents
PLASMA VOLUME
RED BLOOD CELL
HEMOGLOBIN CONCENTRATION
HEART AND LUNGS
WEIGHTLESSNESS
RED CELL MASS
RED CELL OXYGENATION
SPLEEN
RED CELL DESTRUCTION
O_2 IN RED CELLS
OXYHEMOGLOBIN
KIDNEY
PO_2
ERYTHROPOIETIN
BONE MARROW
STEM CELLS
Spacelab Life Sciences 1

RESULTS OF REGULATORY PHYSIOLOGY INVESTIGATIONS (Concluded)

CIRCULATORY SYSTEM

Regulation of Erythropoiesis

The RBC precursor cells of rodents, which were competent to differentiate into mature RBC's, failed to differentiate during flight.

Red Blood Cell Mass

In human subjects RBC mass decreased, indicating a suppression of erythropoiesis. In rodents RBC mass decreased relative to body mass and RBC mass of ground control rodents. The RBC survival remained unchanged in both humans and rodents.

Iron Kinetics

In humans during flight, the serum levels of iron remained constant, while ferritin levels increased and the RBC incorporation of iron decreased.

After flight the RBC incorporation of iron decreased in rodents, indicating a suppression of RBC production.

IMMUNOLOGICAL SYSTEM/BIOTECHNOLOGY

Lymphocyte Production

With advances in biotechnology, applications such as the use of microcarriers are available to conduct lymphocyte activation studies *in vitro*. These studies indicate that lymphocyte activation at 0 G in the presence of microcarriers was increased 100 percent compared to the 1-G controls, whereas in the absence of microcarriers, activation was depressed 50 percent. This was due to the decrease of interleukin-2 production by macrophages and not the lack of adhesion of T-lymphocytes.

MUSCULOSKELETAL DISCIPLINE

MUSCULOSKELETAL

OVERVIEW

Loss of muscle tissue and bone mineral during space flight occurs in humans and rodents. This loss contributes to complications including a reduced state of physical fitness and a decrease in skeletal strength, which may affect how long humans can safely remain in space. An understanding of the mechanisms causing musculoskeletal alterations is critical for developing countermeasures to reduce or halt possible adverse effects.

Six experiments on the SLS-1 mission investigated the mechanisms responsible for muscle and bone loss.

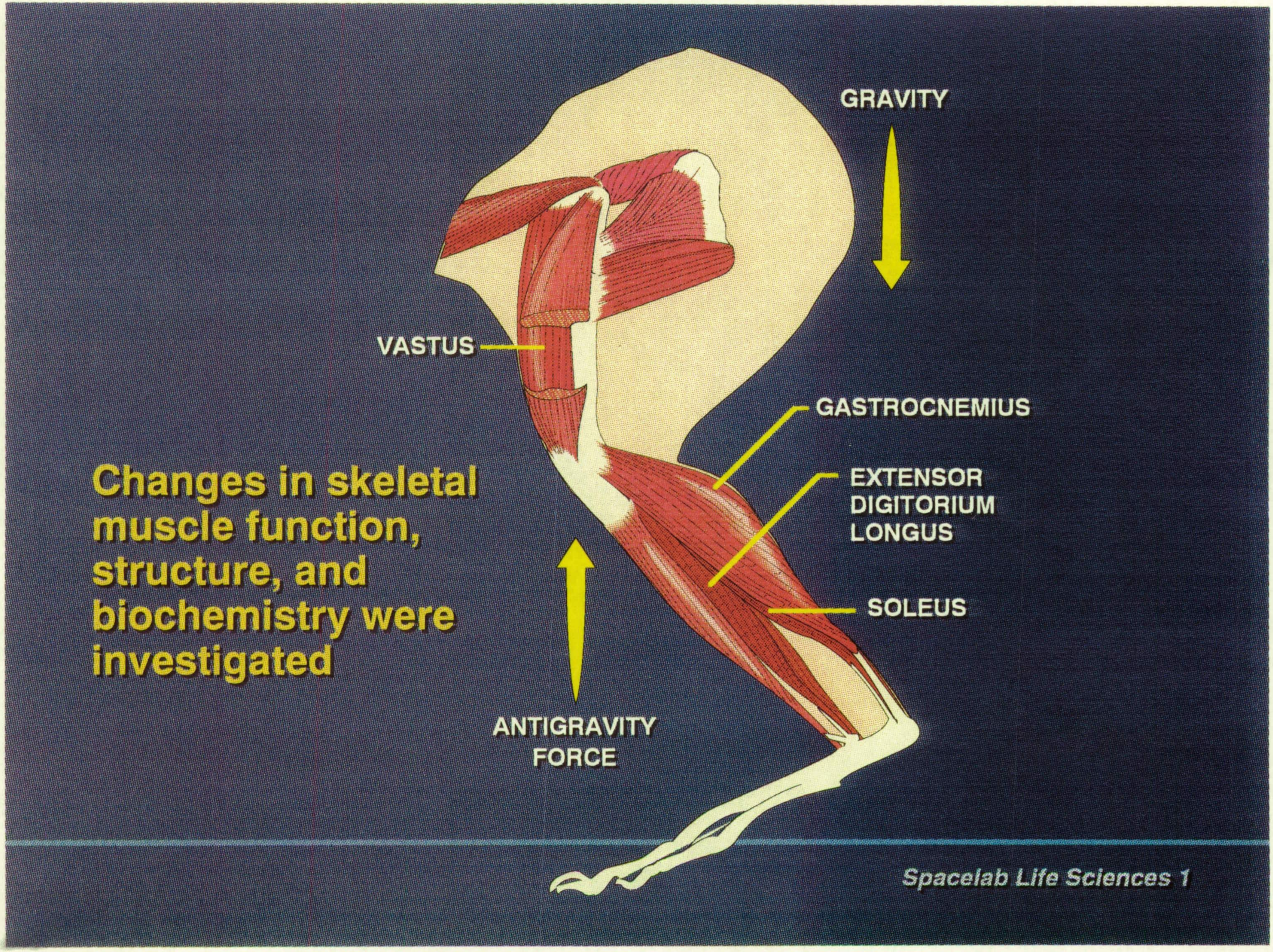
EXPERIMENT OBJECTIVES

Muscular System

- To study protein metabolism by measuring protein synthesis and breakdown rates and nitrogen balance
- To determine how microgravity affects the speed of muscle contractions by studying protein myosin in slow-twitch (antigravity) and fast-twitch (locomotor) muscles
- To compare atrophy rates in the slow- and fast-twitch muscles, and to discover the chemical basis for this atrophy by analyzing the concentrations of enzymes that break down cellular proteins
- To study muscle mass loss and energy utilization in slow- and fast-twitch muscles

Skeletal System

- To study the pathophysiology of bone mineral loss during space flight
- To determine if alterations in bone growth patterns and strength are caused by inhibited bone development or increased bone loss


GRAVITY
VASTUS
GASTROCNEMIUS
EXTENSOR
DIGITORIUM
LONGUS
SOLEUS
Changes in skeletal muscle function, structure, and biochemistry were investigated
ANTIGRAVITY
FORCE
Spacelab Life Sciences 1

RESULTS OF MUSCULOSKELETAL INVESTIGATIONS

MUSCULAR SYSTEM

Protein Synthesis

An increase in protein synthesis occurs during short-term space flight. This increase is associated with a stress response and not a ground-based bed rest response.

Muscle Mass

A significant decrease in rodent muscle mass occurs during flight and is partially replaced by 9 days after flight.

During flight more atrophy occurred in the slow-twitch than in the fast-twitch muscles. After flight the slow-twitch muscles recovered a greater portion of mass than the fast-twitch muscles.

The slow-twitch muscles acquired fast-twitch muscle characteristics, making them less efficient for weight bearing during early phases of recovery.

Muscles show an atrophy-related vulnerability to muscle fiber and microcirculatory damage. These changes are aggravated by postflight reloading in 1 G.

Energy Utilization

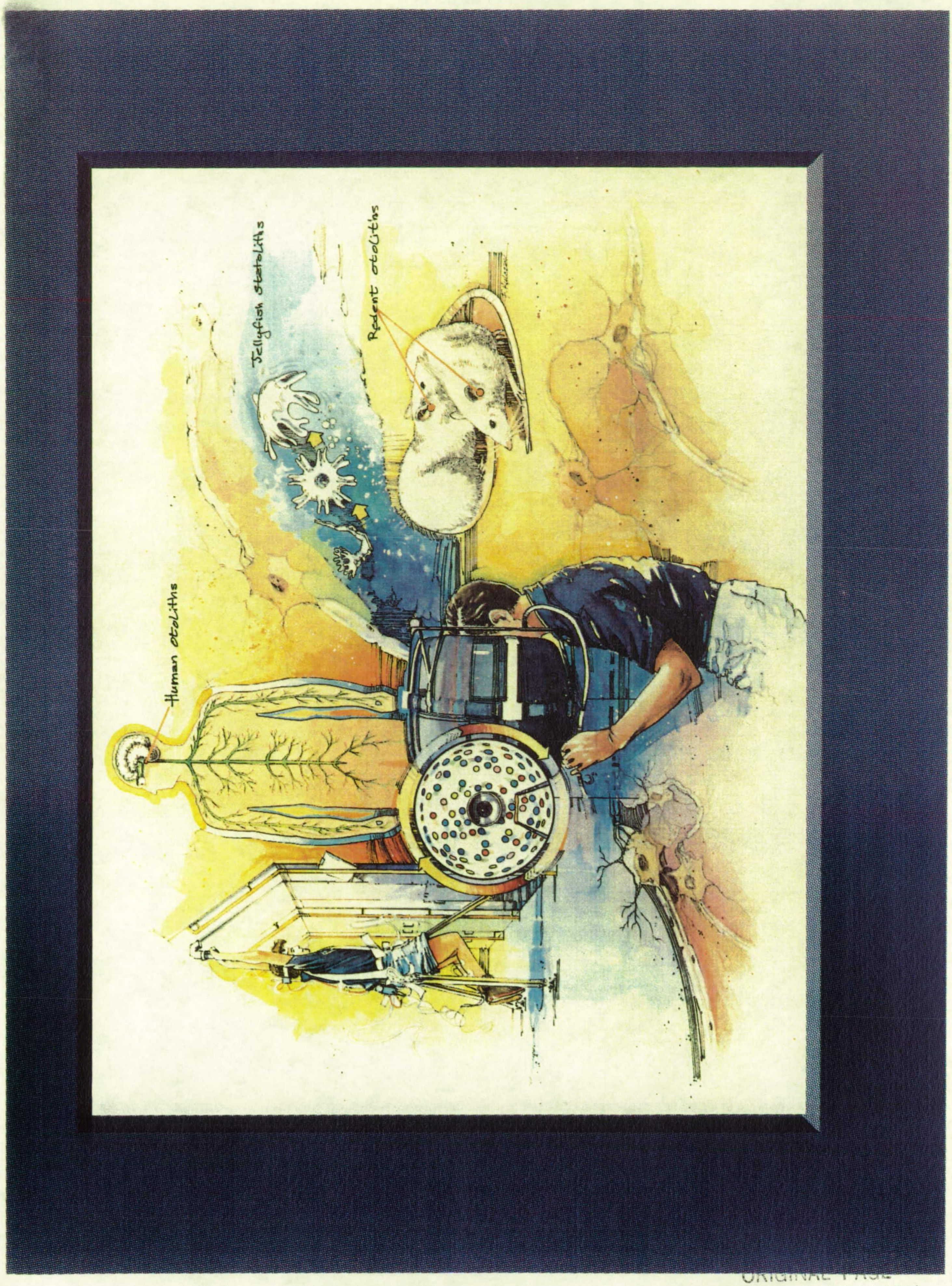
The muscle's ability to utilize certain fatty acids as an energy source is reduced during flight, and the ability is recovered immediately after flight.

SKELETAL SYSTEM

Bone Loss

An increase in serum calcium levels was observed in 0 G. This increase was not attributable to parathyroid hormone levels, which regulate serum calcium levels. Indirect measurement indicates that exposure to weightlessness causes increased bone resorption.

NEUROSCIENCE DISCIPLINE


Human otoliths
Jellyfish statoliths
Rodent otoliths

NEUROSCIENCE

OVERVIEW

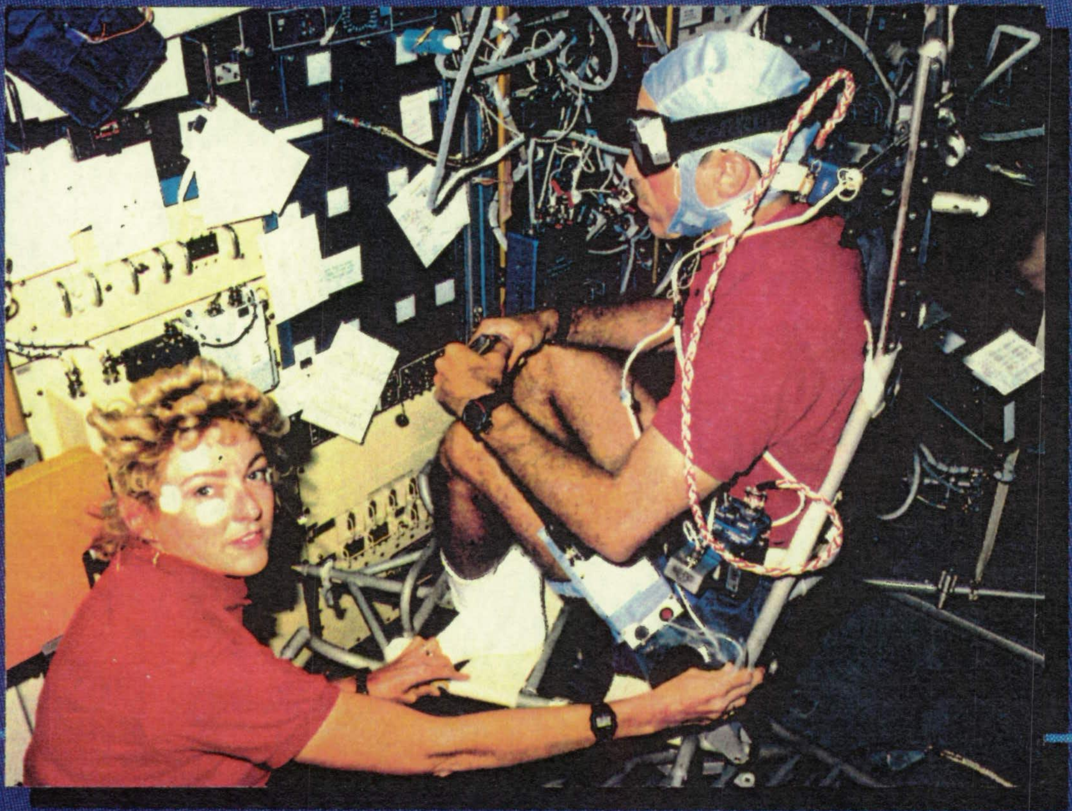
The nervous system requires adaptation to weightlessness to overcome space motion sickness (SMS) and sensory perception conflicts. Early in flight SMS is experienced by a large percentage of astronauts. SMS symptoms are similar to Earth motion sickness symptoms, but scientists are unsure if the stimulus is the same. Discovering and counteracting the mechanisms causing SMS are critical to improving crew efficiency and comfort. Adaptation also includes learning to reinterpret sensory perception. It has been hypothesized that structural changes in sensory organs may play a role in altered sensory perception.

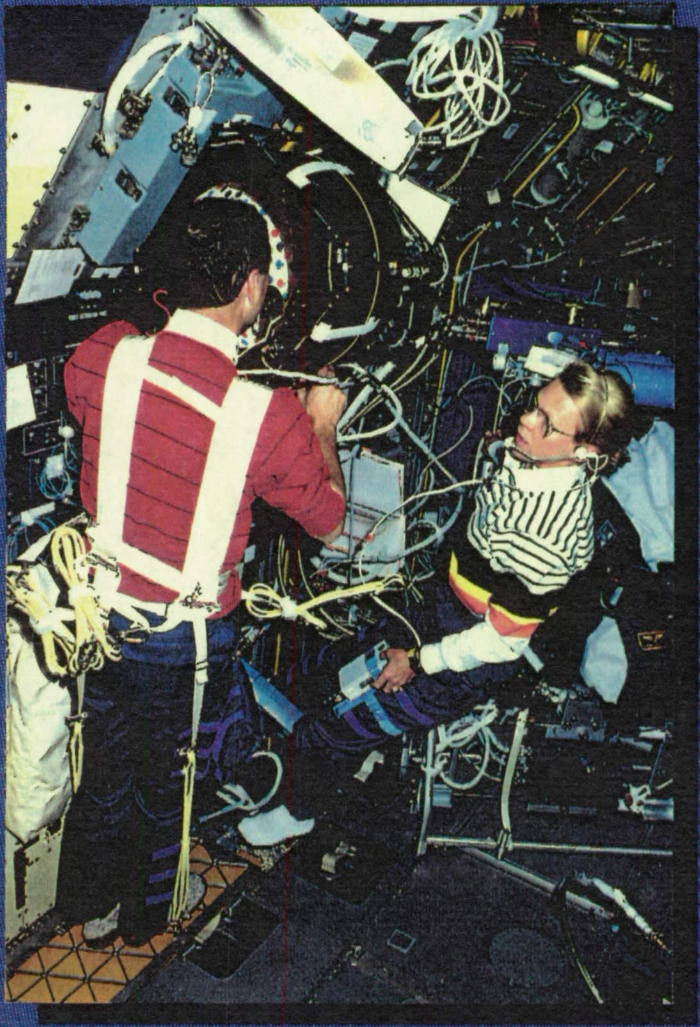
Three experiments were conducted in the Neuroscience discipline.

EXPERIMENT OBJECTIVES

- To investigate the neurovestibular system's adaptation to microgravity and subsequent readaptation to 1 G, including SMS and the interactions and influences of the visual, vestibular, and proprioceptive systems on spatial orientation and posture
- To determine the role that gravity plays in the development of jellyfish, their graviceptors, and their swimming behavior
- To determine if space flight has a detrimental effect on the gravity-sensing organs of the inner ear

Measurements were made to study how the vestibular system relies on visual cues





RESULTS OF NEUROSCIENCE INVESTIGATIONS

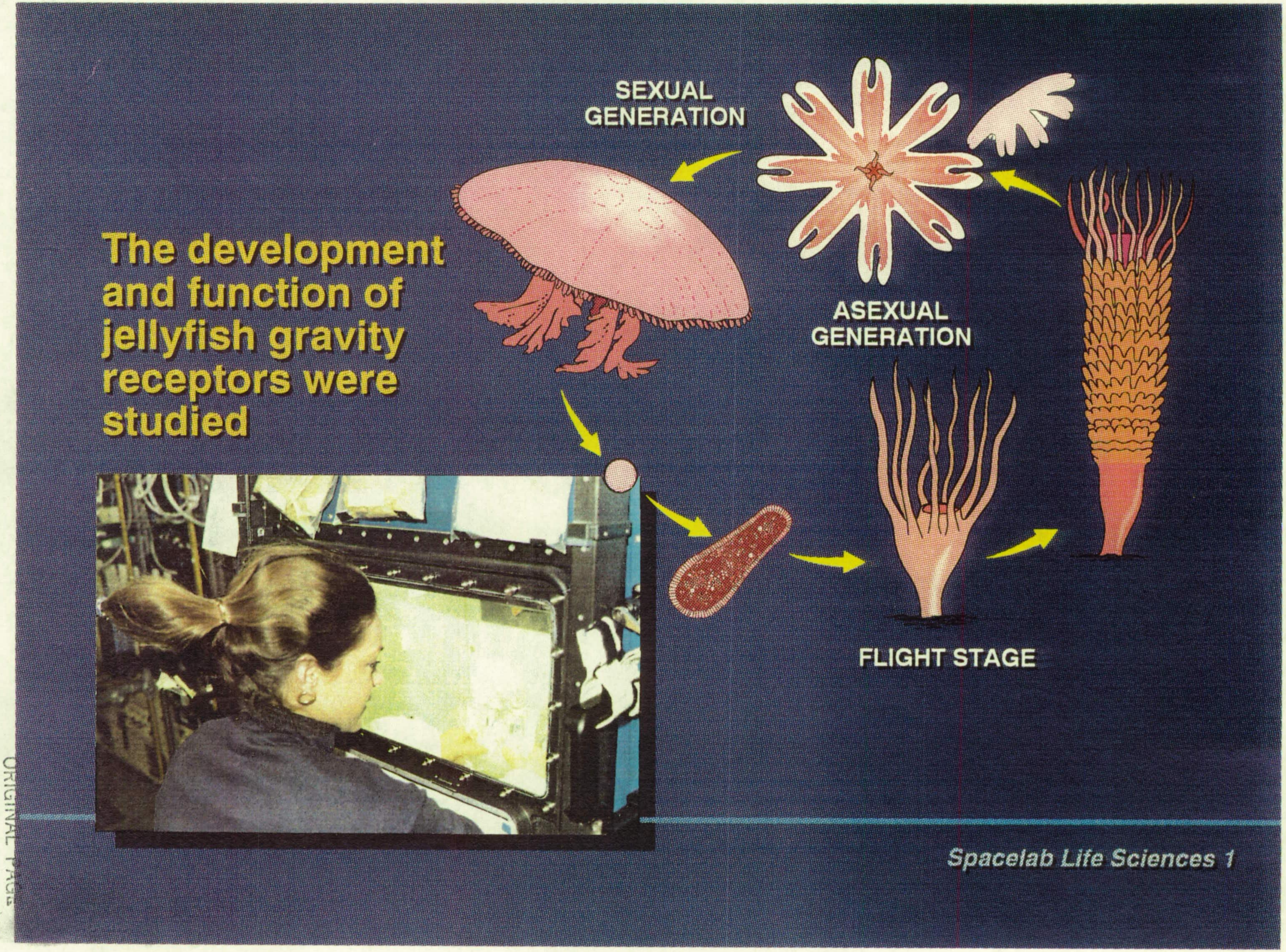
HUMAN VESTIBULAR EXPERIMENT

It was further confirmed that crewmembers who are susceptible to ground motion sickness before flight develop an immunity to ground motion sickness for a period of time after flight.

In weightlessness, the central nervous system primarily uses nonvestibular cues – particularly visual, tactile, and proprioceptive – to maintain the body's sense of orientation. Individual variability was noted in the types of cues relied upon by subjects.

In flight it was more difficult to maintain a mental image of targets with eyes closed, indicating that awareness of position is gravity-dependent. Recovery to preflight level of performance was nearly complete 7 days after landing.

Transient postflight postural instability appears to be caused by a combination of altered muscle and vestibular functions.


The development and function of jellyfish gravity receptors were studied
SEXUAL GENERATION
ASEXUAL GENERATION
FLIGHT STAGE
Spacelab Life Sciences 1

RESULTS OF NEUROSCIENCE INVESTIGATIONS (Concluded)

OTOCONIAL STUDY

Analysis conducted 4 hours after landing demonstrated that the gravity sensing organs, the otoconia, did not demineralize or show other signs of deterioration in rodents.

JELLYFISH DEVELOPMENT AND SWIMMING BEHAVIOR

Jellyfish that metamorphose during flight are capable of generating graviceptors and are able to integrate their neuromuscular systems with their graviceptors to permit complete pulsing contractions and swimming. The swimming behavior exhibited during flight is not consistent with behavior exhibited by 1-G controls.

The intravenous fluid pump test was one of the hardware verification tests conducted in preparation for extended duration space flight

RESULTS OF ADDITIONAL LIFE SCIENCES INVESTIGATIONS

INTRAVENOUS FLUID PUMP

A prototype intravenous (IV) fluid pump for Space Station Freedom operated successfully in 0 G in the manual mode when positive pressure was applied.

MEDICAL RESTRAINT SYSTEM

A medical restraint system (MRS), evaluated for use as a future space flight medical workstation, was successfully used in performing standard physical examinations. The MRS design, however, needs to be reevaluated for increased stability and for microgravity design considerations.

AIRBORNE PARTICULATE MEASUREMENT

The results indicated the particulate mass concentration did not significantly increase with time and was not influenced significantly by the air cleaning system or the animal cages.

SPACE ACCELERATION MEASUREMENT SYSTEM

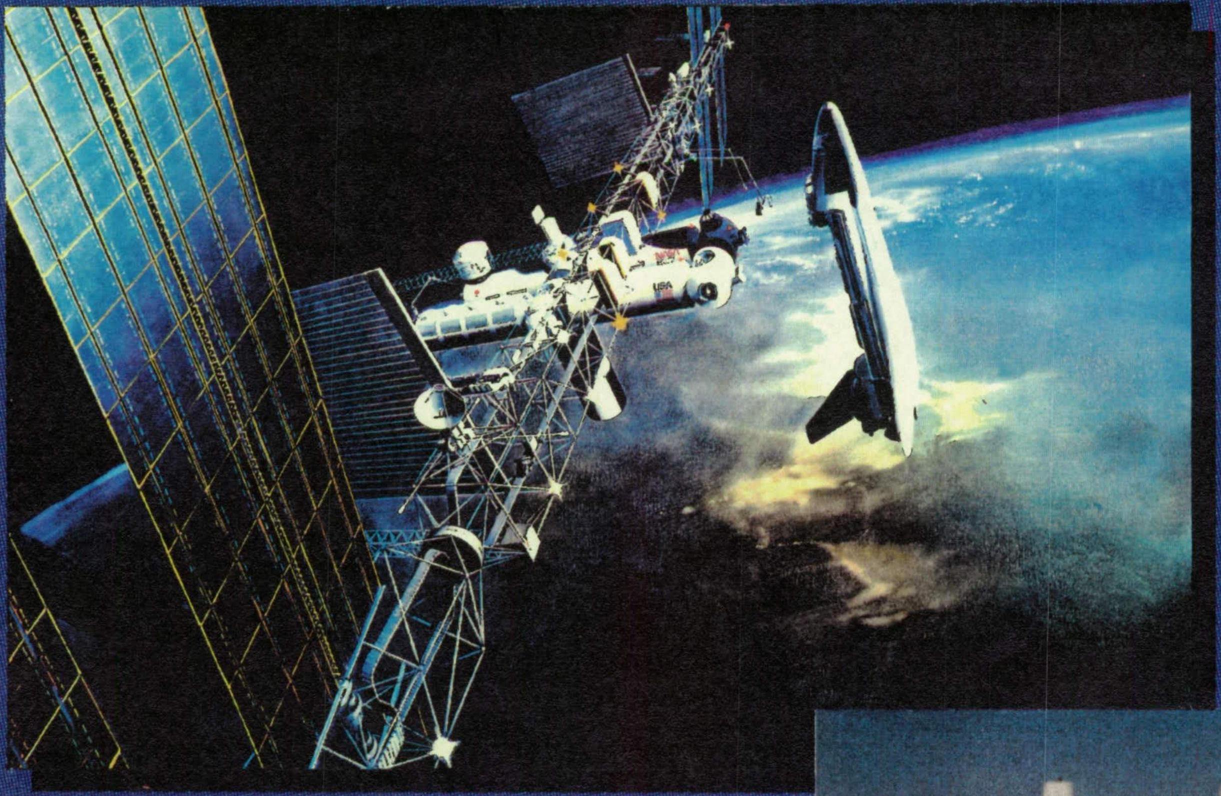
The Space Acceleration Measurement System, which was used to measure the acceleration level effect on experiments, proved to be operationally successful.

BIOSPECIMEN SHARING PLAN

Animal tissue samples were shared with the international community to maximize the scientific return from the specimens flown on SLS-1.

PARTICULATE CONTAINMENT DEMONSTRATION TEST

The Particulate Containment Demonstration Tests (PCDT's) validated the containment capabilities of the rodent hardware. The successful completion of the PCDT's permitted in-flight rodent handling.



The results of the SLS-1 mission will pave the way for ensuring the health, safety, and productivity of humans in space

SLS-1 CONTRIBUTIONS TO FUTURE SPACE FLIGHT

- Data collected on SLS-1 are providing background information necessary to understand physiological adaptation to weightlessness.
- Data collected will contribute to the preparation of future long-duration space flight missions.
- Lessons learned from SLS-1, both scientific and operational, will be incorporated into planning the SLS-2 payload and future SLS missions.
- SLS-1 provided the opportunity to test animal handling and maintenance hardware for in-flight animal experimentation on future life sciences missions.
- The Biospecimen Sharing Program of SLS-1 provided the opportunity for international cooperation in space life sciences research that will be continued on SLS-2 and future missions.
- SLS-2 will provide science enhancement and statistical significance for the data collected on SLS-1.
- SLS-2 is to be launched in mid-1993.

SLS-1 – AN INTERNATIONAL EFFORT

UNITED STATES

Academia

University of California at Irvine
University of California at San Francisco
University of California at San Diego
State University of New York at Buffalo
University of Medicine and Dentistry of New Jersey
University of Texas Southwest Medical Center
University of Tennessee Medical Center at Knoxville
Medical College of Wisconsin
Eastern Virginia Medical School
Massachusetts Institute of Technology
Baylor College of Medicine

Government

NASA
Veterans Administration
National Institute of Health

Industry

GE Government Services
Lockheed Engineering & Sciences Company
Rockwell International, Inc.
KRUG Life Sciences Company
Sverdrup Technology, Inc.
Teledyne Brown Engineering

INTERNATIONAL

Academia

Institut fur Biotechnologie, Switzerland
University of Sydney, Australia
Universite Physiologie de l'Environnement, France
Unite d'Histopathologie Institut Pasteur, France
Laboratoire Ecologie et Physiologie du Systeme Digestif, France
Medizinsche Klinik Innenstadt der Universitat Ziemssentr, Germany
Sechenov Institute of Evolutionary Physiology and Biochemistry, USSR

Government

Centre National d'Etudes Spatiales, France
Canadian Space Agency, Canada
Deutsche Agentur fur Raumfahrtangelegenheiten, Germany
Institute of Biomedical Problems, Russia
Brain Research Institute, Russia
Severtsev Institute of Evolutionary Morphology and Ecology of Animals, Russia
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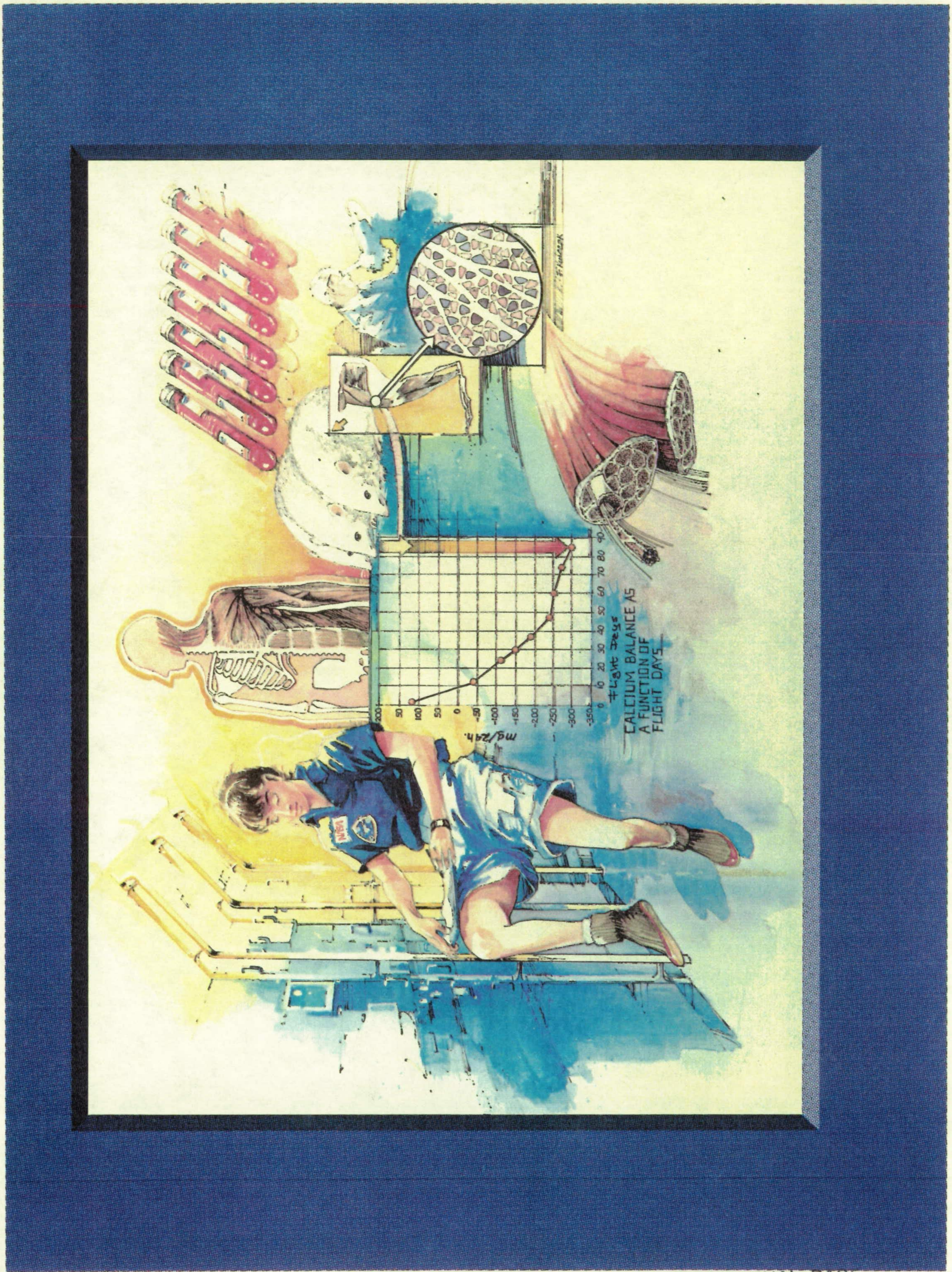
CALCIUM BALANCE AS A FUNCTION OF FLIGHT DAYS
Flight Days
mg/24h.